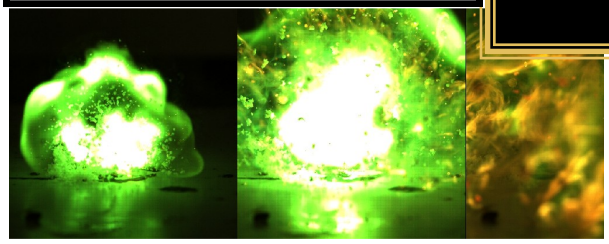
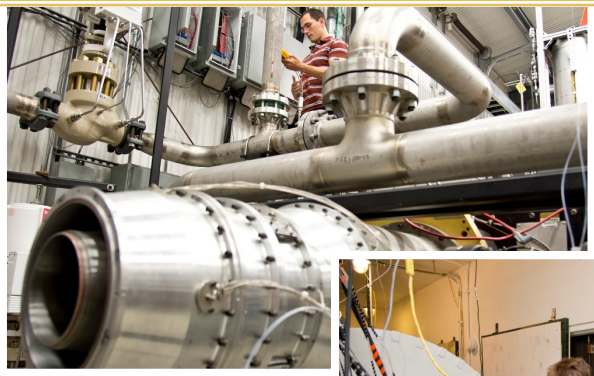
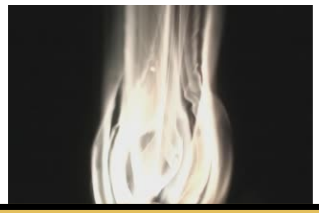
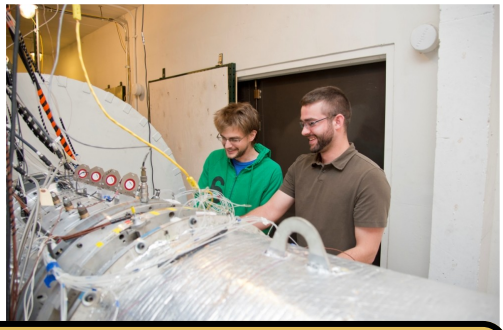
PURDUE UNIVERSITY

2011-2012 ANNUAL RESEARCH REPORT

MAURICE J. ZUCROW LABORATORIES

Schools of Mechanical Engineering & Aeronautics and Astronautics

500 Allison Road, West Lafayette, IN 47907-2014 • Phone 765-494-1501 • Fax 765-494-0530

January 2013

….from the DIRECTOR

Colleagues, Alumni, and Friends of the Maurice J. Zucrow Labs:

I hope that you will enjoy learning about current activities at MJZL with this report. Let me thank our Administrative Assistant, Charlotte Bell, for her many long hours in compiling information that you will find inside. Trying to keep track of the 100+ graduate student at the lab is indeed a full time job. The current MJZL is a multidisciplinary and diverse organization with ongoing research contributions in a broad array of technologies including: wind energy, rocket propulsion, gas turbine propulsion, sprays in consumer products, blood flow in heart valves, energetic materials, coal/biomass gasification, and radiation generated from flames.

The MJZL has had a busy year that featured visits from Missile Defense Agency Chief Administrator, General O'Reilly and numerous members of his staff. We are pleased to have initiated new research projects as a result of these interactions and hope to have expanded activity with MDA in the coming year. Our Multidisciplinary University Research Initiative (MURI) project with the Army Research Office in the area of gelled hypergolic rocket propellants will be wrapping up in the coming year and is generating large activity as we wrap up this work. We have entertained many corporate and government leader visits to the lab as they interact with our students and staff. We also initiated MJZL History Lectures and enjoyed the talks provided by Dr. Ron Derr (Ph.D. '68) and Dr. Mike Murphy (Ph.D. '64) given in September. These gents enjoyed their time here so much that they are spearheading an attempt to provide a *reunion of Zucrow alums* in the coming year. Read more about this in subsequent pages.

A major activity that we have undertaken in the past year is in developing new lab facilities identified as critical to MJZL growth during our strategic planning exercise in 2011. You can read a bit about the details of our plans in the subsequent pages of this report. Purdue has recently initiated a growth in engineering faculty and both ME and AAE schools are currently searching for individuals to augment their current staff. As a result, we anticipate some level of growth in MJZL faculty and student populations in the future. This factor, combined with the successes of our current faculty, provides a strong motivation to develop additional research spaces at the lab.

As a final word, we wish to dedicate some space in this report to commemorate the passing of two of Zucrow's past leaders. Professor emeritus Osborn passed away at the age of 85 on 18 December 2009 and Professor emeritus Ehresman passed away on 22 August 2012 at the age of 90. Please see inside for additional information of the achievements of these men and the mark that they have left on this laboratory.

Thanks and best regards, and of course, Hail Purdue!

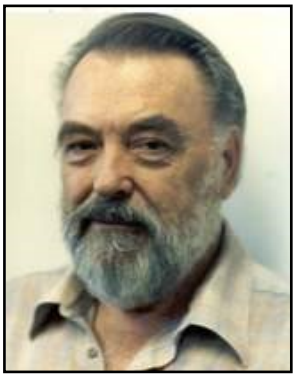
Sincerely,

Stephen (Steve) Heister
Raisbeck Distinguished Professor,
Director Maurice J. Zucrow Laboratories, and
Fellow of the American Institute of Aeronautics and Astronautics (AIAA)

In Memory of . . . . .

John Robert Osborn
1924 – 2009

Professor John Robert (Bob) Osborn died on Friday, December 18, 2009 at Home Hospital in Lafayette. He was born on August 11, 1924 in Kansas City, Missouri. Professor Osborn enlisted in the United States navy as an aviation cadet in August of 1942 and was honorably discharged on December 17, 1945. He entered Purdue University in September 1946 and received a Bachelor of Science degree in Mechanical Engineering in June, 1950. He then worked for Thiokol Corporation of Huntsville, Alabama as a junior engineer dealing with rocketry and solid propellants. He returned to Purdue for graduate study in Mechanical Engineering in September of 1951, and received his MSME in June, 1953. He continued study toward the Ph.D, working with the famous Professor Maurice J. Zucrow and his group of rocket scientists. He completed his Ph.D. in Mechanical Engineering with his June 1957 thesis entitled "An Experimental Study of Combustion Pressure Oscillations in a Gaseous Bipropellant Rocket Motor."

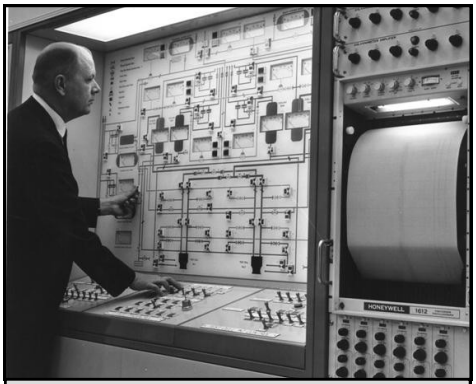


Professor Osborn then joined the faculty of the Purdue School of Mechanical Engineering and was subsequently promoted to the rank of Professor. He served in Mechanical Engineering until transferring to the Purdue School of Aeronautics and Astronautics in 1980. Professor Osborn retired in May of 1989. Professor Osborn taught courses in the propulsion area and conducted research in the general area of solid propellant rockets. Many of his students (or as he termed "his children") were leaders in the aerospace industry (Martin Marrietta - now Lockheed Martin, Thiokol - now ATK, Rocket Research - now part of Aerojet, Air Force Rocket Propulsion Laboratory, Naval Air Weapons Station at China Lake, etc.). Many of his students have also become well known and respected members of the academic world.

Professor Osborn received the prestigious American Institute of Aeronautics and Astronautics *Wyld Propulsion Award for Outstanding Achievement in the Development or Application of Propulsion Systems* in 1995. A true "rocket scientist," Professor John Robert Osborn was a gifted scholar and educator, and is missed by his many colleagues and students.

Charles M. "Chuck" Ehresman
1922 – 2012

Charles M. "Chuck" Ehresman, 90, of Montmorenci, IN, died at 3 PM, Wednesday, August 22, 2012, at St. Elizabeth East. He was born, May 23, 1922, in Elkhart, IN to the late Henry Phillip & Wilhelmina Charlotta Elizabeth (Swanson) Ehresman. Ehresman received his master's degree working under Zucrow in 1951. Upon graduating from Purdue, he went on to Aerojet General Corporation, where he worked on a number of early rocket programs at the Aerojet location in Azusa, California. He worked on some of the early U.S. missile programs serving critical functions as a test engineer.



Chuck Ehresman at the HPL Control Panel (circa 1965)

In 1964, Doc Zucrow recruited Mr. Ehresman to return to Purdue to work with the group at the Thermal Sciences and Propulsion Center (now called the Maurice Zucrow Laboratory). He initially was a visiting assistant professor, and in 1966 was promoted to associate professor of Mechanical Engineering. Doc Zucrow had secured funding from NASA under the Apollo program to build a new lab to study high pressure staged combustion rocket engines. Mr. Ehresman was given responsibility for the design and construction of the MZL High Pressure Rocket Laboratory (HPL). This laboratory was the premier university facility capable of performing single element rocket or gas turbine combustion experiments on even the largest of engines. Even today, no other university lab can match the pressure levels and propellant flowrates attainable at HPL. From 1977 to 1981, he served as Operations Manager of the Thermal Sciences & Propulsion Center. He was currently Professor Emeritus of Mechanical Engineering.

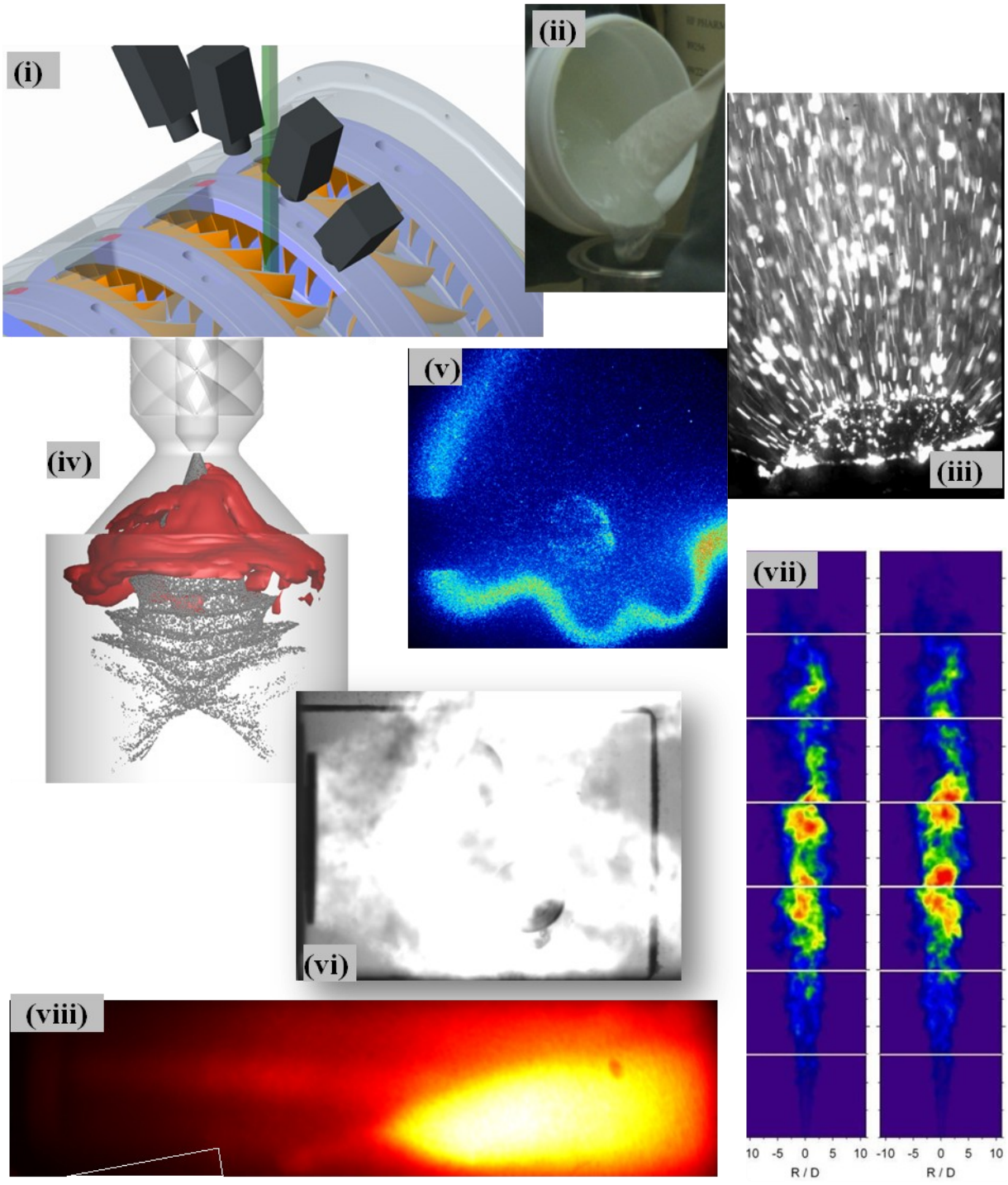
2011-2012 Research Highlights

MJZL Research expenditures are summarized in the chart and table below. The lab continues to be very active, and a global view shows heavy funded activity in 15 of our 16 test cells and high utilization of general lab space as well. In rough measure the lab is spending about $8M in research funds per year. Major sponsors include: ARO, GE, Rolls-Royce, DTRA, Siemens, NIH, MDA, Sandia, GM, Caterpillar, CCTR, and ONR. The following page provides some highlights of recent research results from some of the programs.

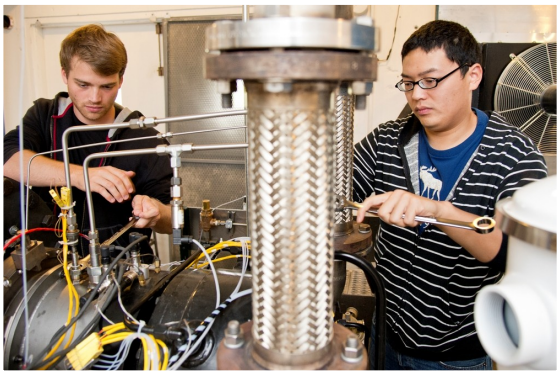
Project	Faculty Investigators	Annual Budget
ARO MURI Gelled Propellants	Anderson, Heister, Lucht, Sojka, Son, Pourpoint	$1.6M
High Mach UTC	Heister, Sojka, Meyer	$300K
Various Gas Turbine Projects	Anderson, Lucht, Heister	$1.5M
Various Rocket Projects	Anderson, Heister, Pourpoint, Meyer	$1.2M
Hydrogen Storage	Pourpoint	$100K
Energetics	Son, Groven, Pourpoint	$1.5M
Compressor and Turbo Machinery	Key	$1M
Cavopulmonary	Frankel, Chen	$220K
Various Computational	Frankel, Chen	$300K
Graduate Student Support	Gore	$75K
Undergraduate Student Support	Gore	$25K
Rolls-Royce Rules and Tools	Sojka, Meyer	$300K
Heat Recovery	Gore	$50K
Jet Ignition in Automotive Engine	Qiao	$100K

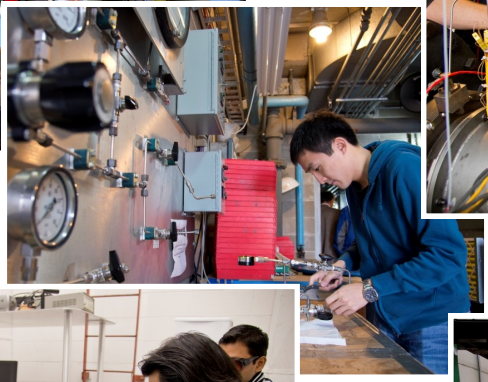
MJZL Research Highlights (cont.)

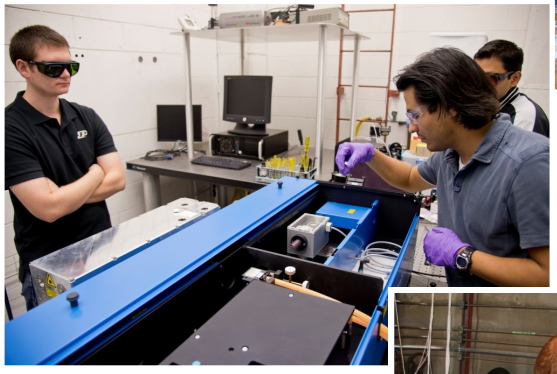
Research Collage:(i) PIV setup for tip clearance flow measurements in axial compressor rig (Profs. Chen/Key); (ii) Gelled monomethyl hydrazine (Profs. Pourpoint/Campanella); (iii) Solid propellant combustion of Al/PTFE fuel (Profs. Son/Groven); (iv) Simulation of heat release from gas turbine injector (Prof. Anderson); (v) PLIF of gelled MMH drop combustion (Prof. Lucht/Son/Pourpoint); (vi) Visible image of high pressure gas turbine combustion (Prof. Lucht); (vii) Infrared radiation intensity from methane/hydrogen/nitrogen turbulent jet flame (Prof. Gore); (viii) Supersonic combustion behind ramp-type injector (Profs. Anderson/Heister).

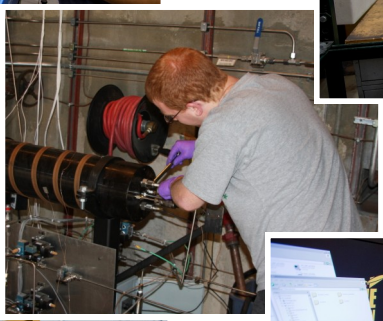


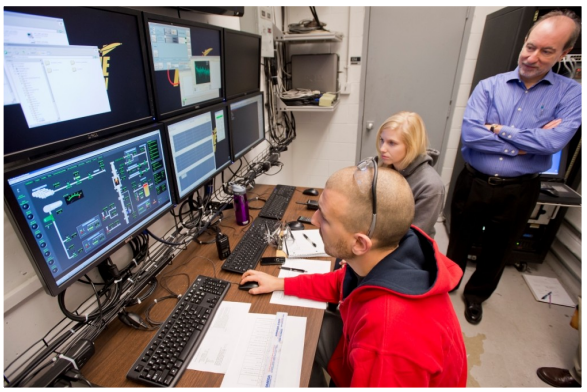
MZL Students—Hard at Work











Zucrow Students Association (ZSA)

In September of 2011, Professor Heister solicited inputs from students in forming a local association at MJZL. The ZSA was created to serve and represent the interests of Zucrow students and faculty by providing historical context to lab activities, organizing social events, and maintaining resources for all students consistent with the research and development mission of our historic laboratory.

Volleyball Champs 2012

In general, ZSA envisions reaching out to local grammar schools to encourage students to pursue STEM related careers, undergraduates to pursue a higher education, teachers to supplement their curriculum, and the community to increase our exposure as a group doing cutting edge research. The student development program will focus on monthly presentations. Each month, 3 students will present a 5-10 minute topic related to their current work. This will offer students the ability to practice in front of an audience of their peers for conferences with feedback to strengthen their speaking ability. Consequently a new forum for the exciting research being done at Zucrow will be created.

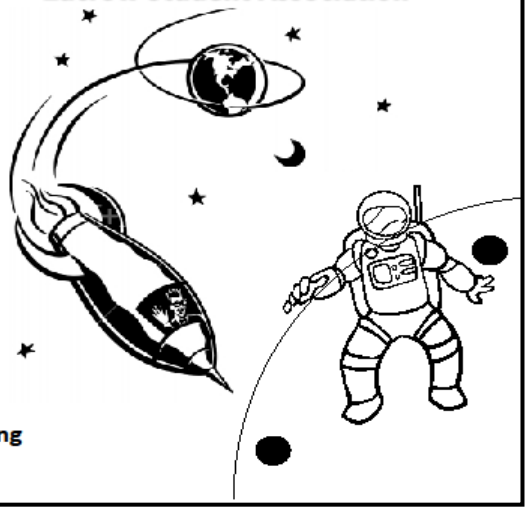
Half Marathon Runners

The ZSA outreach efforts have included travel to a local jr. high school to conduct a water bottle rocket launch with the students. The visit began with a presentation of exciting aspects of a career in the aerospace industry, a brief overview of rocketry fundamentals, and instructions needed for helping the students build the highest performing rockets possible using 2 liter soda bottles. The short lesson was followed by supervising the students constructing and launching their own personal rockets. The event was well received by the students and teachers. The ZSA plans on conducting similar instructional hands-on activities for K-12 outreach in the future.

Congratulations to the Zucrow Students Association:
1st Place Winner of the
2012 Homecoming Window Painting Contest

A dream is a wish your heart makes...

PURDUE PROPULSION "We Can Fly TOO!"
Zucrow Student Association



Propulsion Engineers Make Dreams A Reality!!

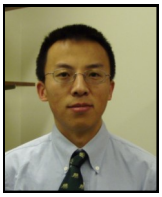
In Memory of Neil Armstrong
1930-2012

ZUCROW LABS FACULTY

John Abraham, Professor of Mechanical Engineering Research Interests: Multiphase Flows, Combustion, Internal Combustion Engines, Computational Fluid Dynamics. Areas: Combustion, Energy Utilization, and Thermodynamics.

Bill Anderson, Associate Professor of Mechanical Engineering (by courtesy), Associate Professor of Aeronautics and Astronautics. Research Interests: Chemical Propulsion and Design Methodoligies. Research Areas: Systematic and careful combination of analysis and experimentation on injectors, combustors, nozzles, and propellants for both rocket and air-breathing propulsion. Specific research areas include ignition, non-toxic propellants, combined cycle propulsion, combustion stability, fuel cooling, and life prediction.

Sally Bane, Assistant Professor of Aeronautics and Astronautics, PhD 2010, Caltech. Research Interests: gaseous combustion dynamics, detonations, plasma control of combustion instability, hypergolic combustion, pressure-gain combustion, energetic materials, electrostatics and ignition, experimental fluid mechanics and aerodynamics, active flow control/plasma flow control. Research Areas: Combustion, Propulsion, Fluid Mechanics, Aerodynamics.



Jun Chen, Assistant Professor of Mechanical Engineering. PhD 2004, Johns Hopkins University. Experimental fluid dynamics; development of flow diagnostic techniques; flow dynamics in stratified environment; and turbulent flow measurements and modeling.

Sanford Fleeter, McAllister Distinguished Professor of Mechanical Engineering. Research Interests: Turbomachinery fluid dynamics, Aero-mechanics, Aero-acoustics, Computational fluids. Research Areas: Fluid Mechanics and Propulsion.

Stephen Frankel, Professor of Mechanical Engineering. Research Interests: Combustion, Turbulent reacting flows, Computational fluid dynamics, Aeroacoustics, Multiphase flow. Research Areas: Combustion, Energy Utilization, and Thermodynamics. Bioengineering.

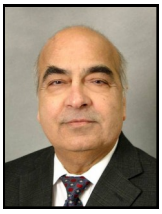
Jay Gore, Reilly University Chair Professor of Engineering and Jefferson Science and Technology Fellow; Research Interests: Combustion, Turbulent reacting flows, Combustion and heat transfer in material processing, and Pollutant reduction. Research Areas: Combustion, Energy Utilization, and Thermodynamics. Bioengineering.

Lori Groven, Research Assistant Professor. Research Interests: Combustion—specifically in the areas of synthesis and materials processing for improvement of energetic materials (propellants, pyrotechnics, explosives). Electromagnetic and acoustic effects in reactive materials. Nanoscale energetic. Advanced energetic materials. Hydrogen generation.

ZUCROW LABS FACULTY (cont.)

Nicole Key, Assistant Professor of Mechanical Engineering, by courtesy in Aeronautics & Astronautics. Research Interests: Aerothermal Aspects of Turbomachinery. Axial and Radial Compressor Performance. Experimental Methods in Fluid Mechanics. Research Area: Fluid Mechanics & Propulsion.

Robert Lucht, Ralph and Bettye Bailey Professor of Combustion in Mechanical Engineering. Research Interests: Laser Diagnostics. Diode-laser-based Sensors. Gas Turbine and Internal Engine Combustion. Materials Processing and Synthesis. Combustion Science. Fluid Mechanics and Heat Transfer. Research Areas: Combustion, Energy Utilization, and Thermodynamics. Fluid Mechanics & Propulsion.



Hukam Mongia, Professor of Mechanical Engineering. Research Areas: Combustion, Energy Utilization, and Thermodynamics.

Tim Pourpoint, Research Associate Professor. Research Interests: Aerospace propulsion systems,. Rocket engine combustors. Liquid propellant injection systems. Hypergolic propellants. High pressure and hydrogen storage systems.

Li Qiao, Assistant Professor, Aeronautics and Astronautics. Research Interests: High-performance fuels for high-speed propulsion systems, alternative and synthetic fuels, fuel synthesis by coal/biomass gasification, endothermic fuels, nanoscale energetic materials, laser diagnostics, experimental fluid dynamics, supersonic and hypersonic combustion, and advanced propellant and propulsion concepts.

Paul Sojka, Professor of Mechanical Engineering. Research Interests: Spray and spray measurements. Fluid mechanic instability. Reseach Areas: Combustion, Energy Utilization, and Thermodynamics.

Steve Son, Professor of Mechanical Engineering. Research Interests: Multiphase combustion, particularly related to propellants, explosives, and pyrotechnics. Nanoscale composite energetic materials. Advanced energetic materials. Microscale combustion. Research Areas: Combustion, Energy Utilization, and Thermodynamics.

ZUCROW AFFILIATE FACULTY

Doug Adams, Kenninger Professor of Renewable Energy and Power Systems, Mechanical Engineering; Affiliate of the Division of Environmental and Ecological Engineering.

Gregory Blaisdell, Associate Professor for the School of Aeronautics & Astronautics.

Osvaldo Campanella, Professor of Agricultural & Biological Engineering.

Carlos Corvalan, Associate Professor of Mechanical Engineering (by Courtesy), Associate Professor of Food Science.

Timothy Fisher, Professor of Mechanical Engineering.

Klein Ileleji, Associate Professor of Agricultural & Biological Engineering.

Fabio Ribeiro, Professor of Chemical Engineering.

P. Veeraragha Ramachandran, Professor of Chemistry.

David Stanley, Associate Professor of Aviation Technology.

Alejandro Strachan, Associate Professor of Materials Engineering.

John Sullivan, Professor & Director of the Center for Advanced Manufacturing.

Jerry Woodall, Barry and Patricia Epstein Distinguished Professor of Electrical and Computer Engineering.

F. Zhao, Assistant Professor of Mechanical Engineering.

Cecil F. Warner Conference Room in Chaffee Hall

ZUCROW LABS STAFF

Steve Heister, Director Maurice J. Zucrow Laboratories. Raisbeck Engineering Distinguished Professor

Scott Meyer, Managing Director Maurice J. Zucrow Laboratories

Rob McGuire, Supervisor of Technical Services

John Fizel, Machine Shop Coordinator / Building Deputy

Charlotte Bell, Administrative Assistant to the Director

Michelle Kidd, Research Account Specialist

Starr Crystal, Business Services

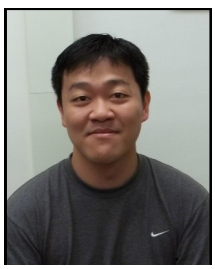
Joan Jackson, Business Services

Michael Bedard, Propulsion Engineer

ZUCROW POST DOCS & VISITING PERSONNEL

Vinicio Magi
Visiting Researcher

Tyler Voskuilen
Post Doc



Changjin Yoon
Post Doc

Andreas Zeiner
Visiting Scholar

It's a Maurice J. Zucrow Labs* Alumni Reunion!

**AKA: Rocket Labs, JPC, Thermal Sciences and Propulsion Center*

Who: Alums of Thermal Sciences and Propulsion Center (now called MJZL) who obtained graduate degrees from the Laboratory (spouses/significant others are welcome).

What: Opportunity to meet old friends and make new ones, observe current research projects at the labs, attend a football game, etc. *This could even be a good opportunity to gather with classmates around the scheduled reunion events.*

When: September 6 & 7, 2013

> ***Friday, 6 Sept***. Reception and Reunion Dinner (7:00 p.m.) with overview from Maurice J. Zucrow Lab (MJZL) Director and more. Lab luncheon and open house in the afternoon for those arriving earlier in day.
>
> ***Saturday, 7 Sept***: Breakfast with current MJZL students and staff and lab tours. Transportation to/from Purdue vs. Indiana State football game. Informal evening gathering at local establishment TBD.

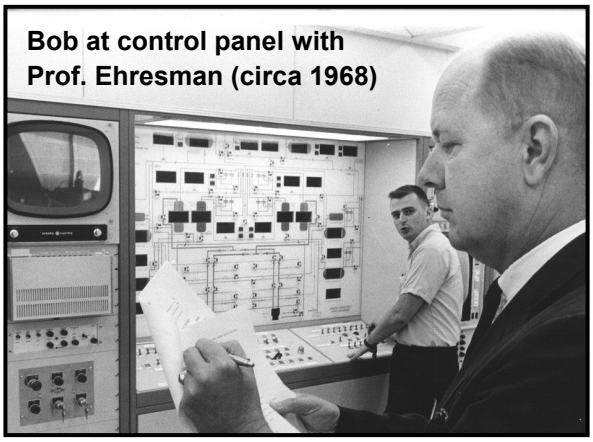
Where: MJZL of course! Accommodations at Union Club Hotel on campus or Hilton Garden Inn on the Wabash Landing (blocks of rooms are reserved at these two locations for this event; however, feel free to obtain other accommodations in the area, depending on availability. You can reserve your room at the Union Club Hotel *(They are not taking reservations for this event until April 1, 2013.)* or the Hilton Garden Inn by calling and giving them the Group Code as follows:

Purdue Union Club Hotel on campus: 1-800-320-6291; Group Code: Zucrow Labs Alumni Reunion. Reservations can be made April 1—August 23, 2013. Cost is approximately $125/night + applicable state and local taxes, and there is NOT a 2-night minimum stay. (Thursday night might be included in this block for $99/night – more info later.)

Hilton Garden Inn, Wabash Landing, West Lafayette (within a few blocks of campus): 1-765-743-2100; Group Code: LABS. The cut-off date for this room block is July 5, 2013 (2 months prior to the event). Cost is ~$229/night + applicable state and local taxes. Note: 'Special Event Policy' applies at this location which requires a 2-night minimum stay (Friday & Saturday).

Organizers: Dr. Mike Murphy (Ph.D. '64), Dr. Ron Derr (Ph.D. '68), Dr. Bob Strickler (Ph.D. '68).

How do I sign up?: Please email Mike (mmurphypci@aol.com), Ron (ronderr1@mac.com), or Bob (FairWinds1@aol.com) and provide phone number or email for contact. ***More information regarding the event will be available at a later date.***



Bob at control panel with Prof. Ehresman (circa 1968)

Ron and Mike in front of Armstrong Hall (Sept. 2012)

MJZL Development Plan - Air System and Building Upgrades

Historical Context

Purdue has a rich history in the study of gas turbine combustion dating back to the research of Arthur Lefebvre in the 1970's and 1980's. After Lefebvre's retirement in 1991, the gas turbine work at HPL withered as new faculty hired in Mechanical Engineering had differing research interests. In 2001, Professors Heister and Gore teamed with Rolls-Royce on a 21st Century Research and Technology Fund proposal that was aimed in part to provide resources for renovation of the High Pressure Lab. Thanks to the leading efforts of Dr. Lynn Snyder of Rolls-Royce (Liberty Works), the group won a $2M proposal that contained roughly $1M for lab renovations and research in pulse detonation and rocket propulsion. MZL Managing Director Scott Meyer was hired with these funds, and facility renovations began in April of 2001. In August of that year, Professor Anderson joined Purdue and helped to shape the plan for the rocket facility. Rather than building a new test cell, Anderson argued that funds should be utilized to create what was to become the nation's most capable university liquid oxygen system. A decade later, and $10M+ in research projects makes it quite obvious that this was a great investment.

The airbreathing propulsion funds were used to upgrade the West Test Cell at HPL, and a pulse detonation engine facility was designed by Meyer and became operational in mid 2002. The air system, which had not been used at high rates in many years, became a matter of concern as these experiments began producing research results. In 2003, a second 21st Century win provided another $1M in funding to expand efforts in airbreathing propulsion. In this same year, Purdue became the nation's first Rolls-Royce University Technology Center as the High Mach UTC came into existence in the summer of that year. Assets were added to the Gas Turbine cell for creating high temperature air (beyond what our current heater can do) at low flows. Valving, instrumentation, and exhaust emissions equipment were purchased in order to upgrade and modernize lab capabilities in this area. In addition, $300K of these funds were invested for refurbishment and modernization of the MZL air compressor system. These 21st Century fund investments have brought over $10M in research funding, and as a result our projects are highlighted as some of the most successful in all of those funded by this State-sponsored institution.

In 2004, Professors Gore and Lucht began to work with Roll-Royce combustion specialists and obtained a $400k investment from the Indiana 21st Century fund to build a low emissions combustor research facility with associated test article. About the same time, the UTC developed a rig based on an existing Rolls-Royce helicopter combustor (RR 501K) as a hot gas source to study injector and nozzle flows. In 2008, Professors Gore and Lucht continued work with Rolls-Royce combustion specialists and obtained NASA funding to construct an optically accessible combustor and make measurements of a low-emissions NASA injector design. In 2006, the UTC received a 4-year, $4M expansion into the area of supersonic business jets and this precipitated the construction of the HPL Annex. Scott Meyer led the development of the ZL-7 facility that substantially relieved congestion in the Gas Turbine Cell. However, this relief was short lived as the assets put in place, combined with the tremendous faculty talent engaged in these endeavors, has led to resurgence in this problem.

In 2008, Prof. Lucht received the first of several grants from Siemens to conduct optical diagnostic measurements of staged combustion processes for power-generating gas turbines. This grant necessitated the development of a high pressure natural gas system on the HPL site. In 2010, Prof. Anderson also began working with Siemens and built a second Siemens rig in the Gas Turbine Cell. Profs. Lucht and Anderson also received a grant from the US Department of Energy's University Turbine Systems Research (UTSR) program in 2011.

In terms of aviation gas turbine research, Prof. Lucht has received significant funding from GE

MJZL Development Plan—Air System and Building Upgrades (cont.)

Aviation in Cincinnati, Ohio to develop an optically accessible test rig for studying GE's latest generation of combustion technology. Most recently, Drs. Anderson, Merkle, Lucht and Mongia were awarded a grant from NASA Glenn Research Center. The competition for this award was intense. While Georgia Tech had anticipated taking this prize, the Purdue team prevailed.

Table 1 summarizes current research contracts that are secured for work within the Gas Turbine test cell at HPL. This combined activity document Purdue's position as a contender to become the preeminent gas turbine combustion lab in the nation. However, this activity level demands that over $6M in work must be conducted in the next 2.5 years. Figure 1 documents the current orientation of the Gas Turbine Cell noting the installation of four separate rigs at the present time. The Gas Turbine Cell is operating at 200-300% capacity, and we are risking missing major research milestones as students and staff struggle to maneuver optical diagnostics and conventional instrumentation amongst six different experiments from three different gas turbine companies and two federal agencies. The spray diagnostics rig is presently planned to be located in the back of the East Test Cell, but there is precious little real estate in this cell, as well as our large liquid oxygen rocket stand has a substantial footprint. The latter four projects (three of which are already funded) on this list ***have no home at present***. There is an urgent, near-term need to relieve this problem, and we must act quickly, as near-term milestones can be affected.

Table 1: Current-Projected HPL Projects Demanding High Temperature Air

PIs	Sponsor	Start/end dates	Total Budget, $K
Heister, et al	Rolls-Royce UTC	01/01/12-12/31/13	750
Heister /Meyer	Rolls-Royce VCAT	06/01/12-05/31/13	287
Anderson, et al	NASA	06/14/11-06/13/14	900
Anderson	Siemens	11/01/10-03/31/13	230
Lucht	Siemens	10/01/10-09/25/13	650
Lucht	GE	03/01/11-12/31/13	800
Lucht/Anderson	DOE	10/01/11-09/30/14	443
Sojka/Meyer	AFRL/R-R	01/01/12-12/31/12	300
Chen	GE	TBD	TBD*
Fisher/Heister	AFRL	01/01/13-12/31/15	285
Xu/Heister	DOE	09/01/12-08/31/15	736
Lucht	GE-Research Ctr	1/1/13-12/31/13	150
Total			**5541**

* Still Tentative, We have not identified available space for items in red

MJZL Development Plan—Air System and Building Upgrades (cont.)

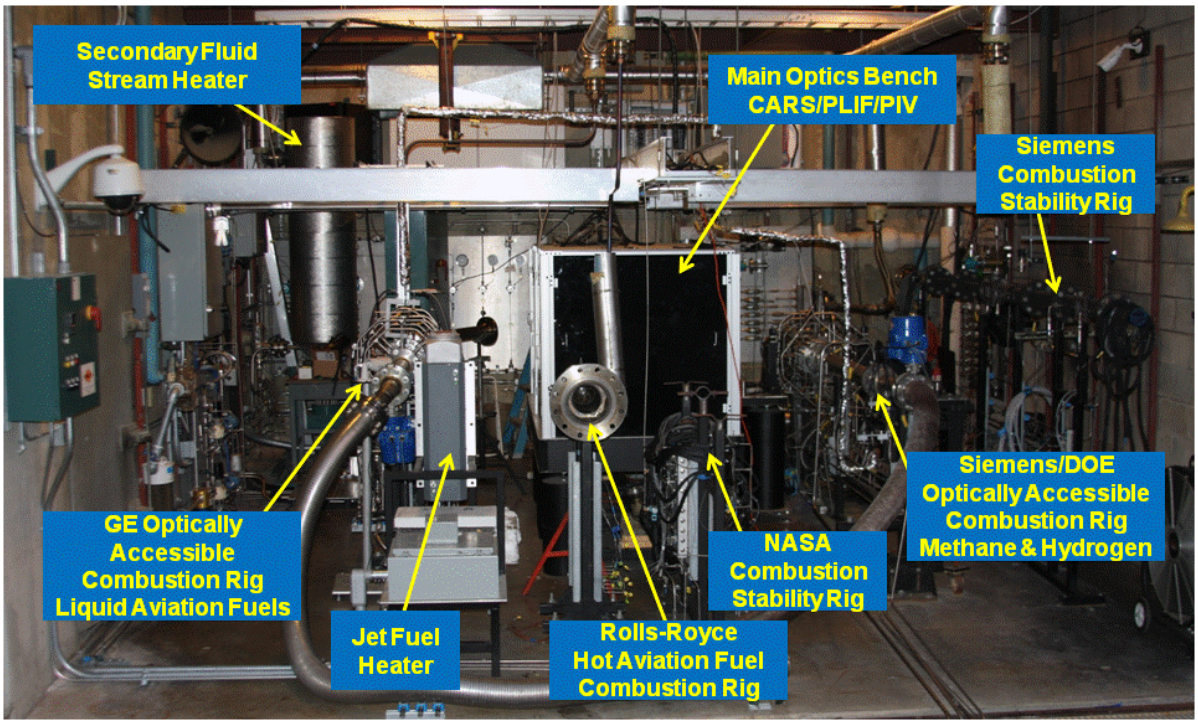


Figure 1: Current view of the Gas Turbine Cell at HPL

The heated air system at MZL is the nation's most capable, but unfortunately, it is nearly 50 years old and has become outdated relative to current engine technology. Figure 2 provides an image of the high capacity air heater and the resultant flow capability at various temperatures. When the system was built, it was capable of delivering high flows at temperatures and pressures of the 1960's era gas turbine engines delivering temperatures in excess of 900 F to test articles. However, in the past five decades gas turbine compressor pressure ratios have more than tripled and resultant compressor discharge temperatures in modern engines can exceed 1400 F. In addition, high Mach flight conditions in excess of Mach 3 require these higher temperatures as well. A new air heater will not only relieve congestion in the gas turbine cell, but will also permit researchers to reach temperatures that our research sponsors desire.

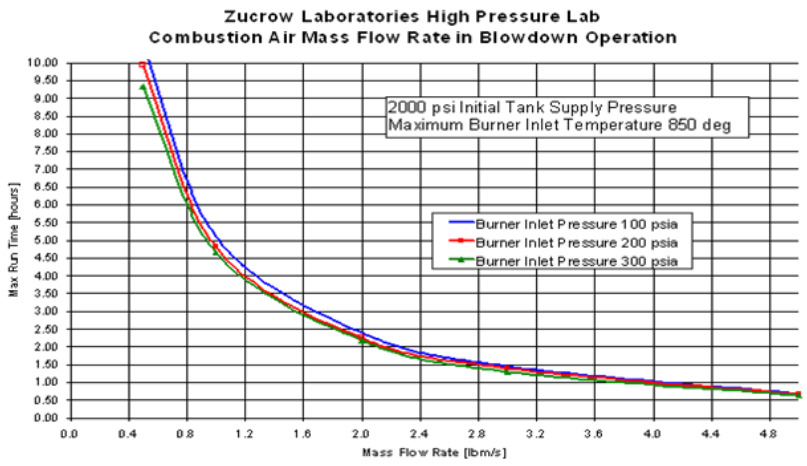


Figure 2: Current MZL Air Heater (r) and Performance at Various Flowrates (l)

MJZL Development Plan—Air System and Building Upgrades (cont.)

Our recent work has highlighted Prof. Lucht's development of Coherent Anti-Stokes Raman Spectroscopy (CARS) with application to gas turbine combustion processes at high pressures. The MJZL is the only lab in the world making these unique measurements that give local temperature and species in the arduous environment in a high pressure gas turbine combustor. Figure 3 provides an image of recent CARS setup at HPL.

Facility and Infrastructure Development Plan

Over the past 14 months, we have spent substantial time learning of requirements for additional spaces and have developed a plan that involves three major elements:

1. Purchase and installation of a new, higher temperature air heater
2. Design and construction of a new laboratory with four new test cells to support repositioning and expansion of heated air experiments
3. Refurbishment and expansion of the north end of the High Pressure Lab where offices, control rooms, and buildup areas are contained.

Figure 4 highlights the elements of the proposed development within the existing HPL complex.

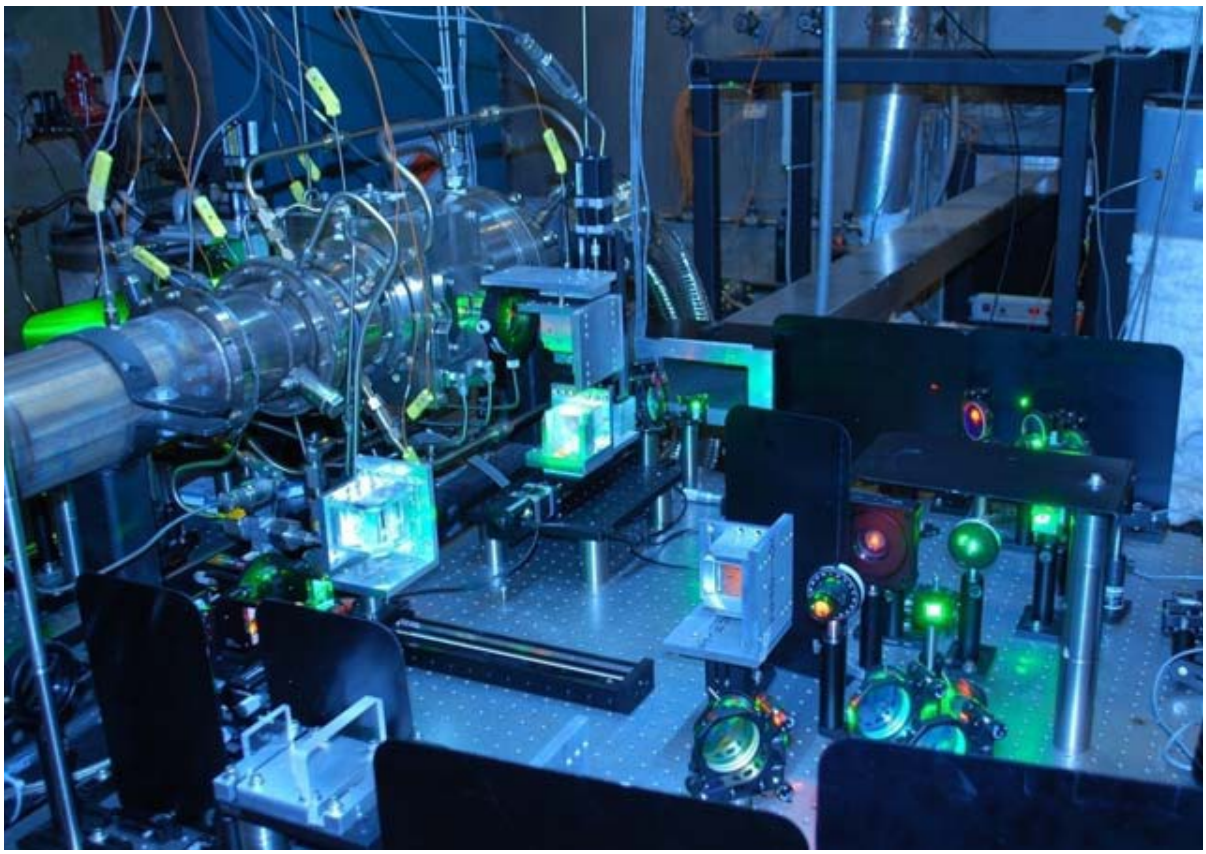


Figure 3: CARS Setup in HPL During 2010 Test Campaign

Phase 1: New Air Heater for HPL: We have solicited a price quote for a new heater with 1500 degree F capacity and 63% thermal efficiency from a firm named Thermal Transfer, Inc. The other elements of the heater installation include concrete pad construction, facilities relocation and hookup, valve procurement, and insulated tubing procurement/installation. We estimate a total project cost of $1.4M for procurement of the system and provisions for heated air plumbing installation.

MJZL Development Plan—Air System and Building Upgrades (cont.)

Phase 2: New Building for Research with Heated Air: MZL Managing Director Scott Meyer has developed a detailed drawing that delineates utility requirements, size, and construction type for the new building. The proposed structure will be mainly of cement construction and has an overall size of 5878 sq. ft. The structure will house five new test cells, all supported by an adjacent laser lab with optical access to each of the five cells. Preliminary University estimates for this building are approximately $3M.

Phase 3: Refurbishment and Expansion of HPL Office/Control Areas: The third element of the plan involves expansion of existing HPL control and office spaces to accommodate the growth in research capabilities. We debated the merits of adding on to the existing lab vs. building a new space, and it became apparent that it would be most prudent to take the latter course (at least for the sake of articulating space needs). The new space will include office and conference facilities, control rooms, and build-up areas for electronics and plumbing. The preliminary University estimate for this phase of the project is $2M.

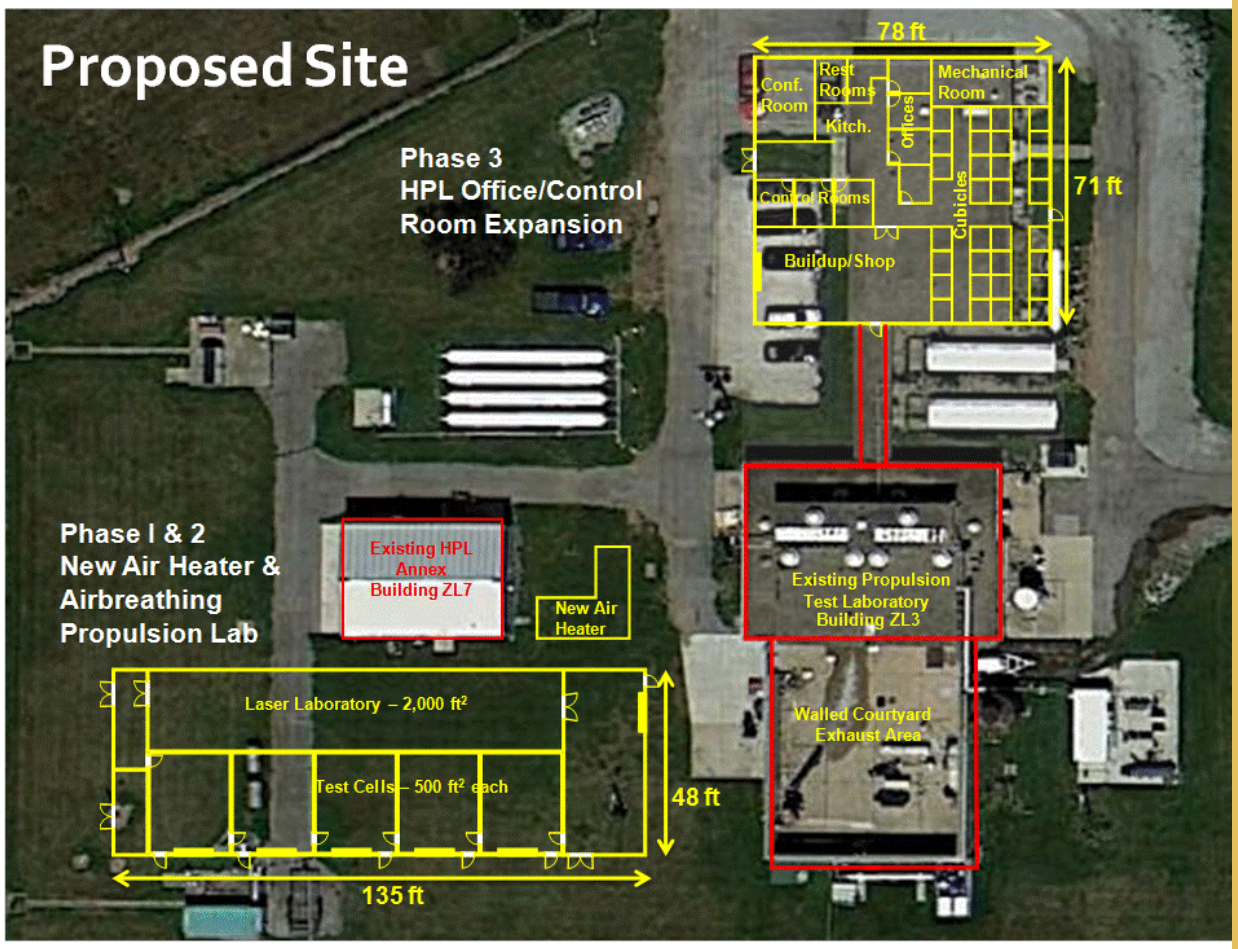


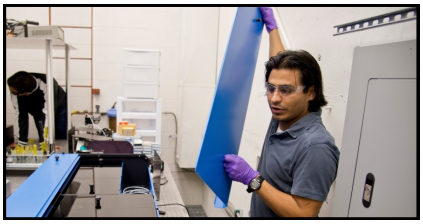
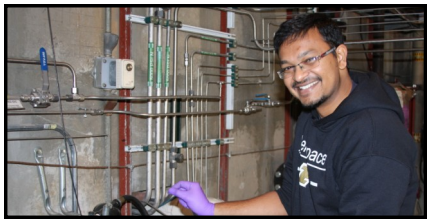
Figure 4: Proposed Air System and Building Upgrades at the MJZL High Pressure Lab

Conclusions

We are moving as rapidly as possible within the university environment to make this strategic plan become a reality. We hope that Zucrow alumni will be interested in partnering with us as we develop a funding plan for the development project.

MJZL CURRENT STUDENTS

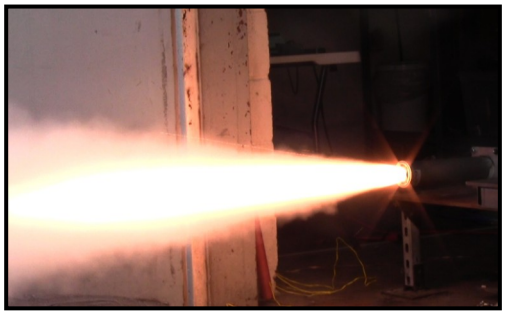
Student	Advisor	Email ....@purdue.edu	Thesis Topic
Ball, Patrick	N. Key	prball	Inlet Distortion Considerations for Multistage Compressor Performance
Bangalore, Prashanth	S. Bane	pbangalo	High-Pressure Combustion and Detonation-to-Degraflation Transition in Ethylene/Nitrous Oxide Mixtures
Beason, Matthew	S. Son	mbeason	
Bedard, Michael	S. Meyer	mbedard	Fiber Optic Spectroscopy of High Frequency Combustion Instability
Berdanier, Catherine	R. Lucht	cberdanier	Subject: Emissions reduction in gas turbine engines with TAPS combustion technology

Berdanier, Reid	N. Key	rberdani	Design of a Multistage Research Compressor for Cantilevered Stator Hub Leakage Flow Investigaztion
Bhuiyan, Aizaz	R. Lucht	abhuiyan	
Biswas, Sayan	L. Qiao	biswas5	Ignition of Ultra-lean Premixed Methane/Air Mixtures using a Hot Turbulent Jet
Brossman, John	N. Key	jbrossman	The Effects of Large Rotor Tip Leakage Flows in the Rear-Block of a Multistage Compressor
Buechele, Kevin	D. Adams	kbuechel	
Camel, Rozzerio	J. Gore	rcamel	Quantitative Experimental and Computational Infrared Diagnostics of Turbulent Reacting Flows Under Water Suppression
Cho, Kevin	S. Son, R. Lucht	kycho	Optical Diagnostics of Gelled Hypergolic Bi-propellants
Chrzanowski, Jonathan	S. Heister, T. Pourpoint	jchrzano	(undecided)
D'Entremont, James	S. Bane	jdentremont	Control of Combustion Instability Using Plasma Discharges
Dadson, Jennifer	T. Pourpoint	jdadson	Characterization of Heat and Mass Transport in Catalyzed Magnesium Hydride Hydrogen Storage Systems
Daily, Megan	S. Son	daily2	Subject: Electromagnetic properties of energetic materials
Dasappa, Shruthi	J. Gore	sdasappa	
Dennis, Jacob	S. Son, T. Pourpoint	dennis4	Subject: The ignition and combustion of advanced hypergolic propellants

MJZL CURRENT STUDENTS (cont.)

Student	Advisor	Email ....@purdue.edu	Thesis Topic
Engerer, Jeff	T. Fisher	jengerer	
Ennis, Brandon	S. Fleeter	bennis	Subject: Aerodynamics and aeromechanics of wind turbines and wind farms
Feddema, Rick	P. Sojka	rfeddema	
Feldman, Thomas	W. Anderson	tfeldman	Hydrogen addition effects on combustion instability in a continuously varying resonance combustor
Fineman, Claresta	S. Son	cfineman	High Shear Rheology of Hypergolic Gelled Propellants
Finney, Heather	P. Sojka	hfinney	Subject: Fluid dynamics of deep water multiphase jets
Forness, Jordan	S. Heister, T. Pourpoint	jforness	Injector Concepts for Hypergolic Propellants
Fox, David	T. Pourpoint	dcfox	Non-thesis
Fugger, Chris	W. Anderson	cfugger	Subject: A reacting jet in an unstable crossflow
Gabl, Jason	T. Pourpoint	jgabl	Solution Combustion Synthesis of Cobalt Catalysts for the Hydrolysis of Sodium Borohydride
Gao, Jian	J. Chen	gao53	Application of Digital Holography to Spray Diagnostics and Zebrafish Embryonic Development Imaging by Digital Holographic Microscopy
Gejji, Rohan	W. Anderson	rgejji	Investigation of Combustion Instability in a Lean Direct Injection Gas Turbine Combustor
Han, Dong	J. Gore	han193	
Heckaman, Bryce	N. Key	bheckama	



Heinz, Nick	Sullivan	nheinz	Experimental Investigation of an Ejector Nozzle Using Forced Mixing Tabs for Supersonic Business Jet Applications
Hester, Sarah	S. Heister	hester1	
Hunt, Steven	S. Heister	hunt54	Thermoacoustic instabilities of supercritical fuel in parallel heated flowpaths
Isert, Sarah	S. Son	sisert	

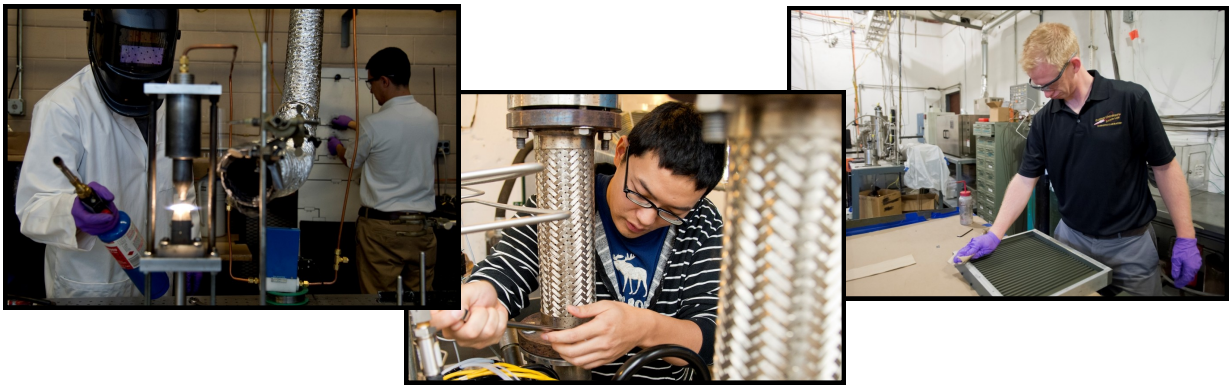
MJZL CURRENT STUDENTS (cont.)

Student	Advisor	Email ....@purdue.edu	Thesis Topic
Juska, Paul	S. Son, W. Anderson	pjuska	Non-thesis
Kan, Brandon	S. Heister	bkkan	Pulse Detonation Rocket Engines
Kapaku, Robert	J. Gore	rkapaku	Quantitative Time-Dependent Radiation Intensity Measurements of Luminous Flames

Kerlo, Anna-Elodie	J. Chen, S. Frankel	akerlo	Development of a Circulatory Support for the Univentricular Fontan Circulation
Kittell, David	S. Son	dkittell	A Water-Based Rocket Propellant Utilizing Aluminum Nanopowder with a Protective Hydrophobic Coating
Kulkarni, Varun	P. Sojka	vkulkarn	Secondary Atomization of Non Newtonian Drops at High Weber numbers
Kumar, Sumeet	S. Heister	kumar94	Waste Heat Recovery in Automobile Exhaust using Thermoelectric Generators: Topological Studies and Performance Analysis
Larson, Logan	S. Heister	larson23	Non-thesis
LeJeune, Daniel	T. Pourpoint	dlejeune	Characterization of Heat and Mass Transport in Catalyzed Magnesium Hydride Hydrogen Storage Systems
Leng, Yujun	S. Fleeter	leng	Multistage interaction in axial and centrifugal compressors
Lou, Fangyuan	N. Key	louf	Inlet Distortion Effects on a High Speed Centrifugal Compressor
Mares, Jesus Jr.	S. Son	maresj	Response of Energetic Materials Under Acoustic Energy Insult
Mason, B. Aaron	S. Son	bamason	Impact Ignition of Intermetialic Materials
McKinney, Emerald	W. Anderson	mckinnee	Non-thesis
Miklaszewski, Eric	S. Son, L. Groven	emiklasz	Oxy-fuel Combustion: Laboratory Experiments and Pilot Scale Tests
Morrison, Evan	N. Key	emorrison	Design of a Calibration Facility for a 3-wire Hot-wire Probe
Mugenda, Angela	S. Bane	amugenda	Combustion Characterization of Fine Hypergolic Sprays

MJZL CURRENT STUDENTS (cont.)

Student	Advisor	Email ....@purdue.edu	Thesis Topic
Murray, William	N. Key	wmurray	Inlet Distortion Effects on Centrifugal Compressor Performance
Nellums, Robert (Ross)	S. Son	rnellums	Subject: Desensitization of nanothermites using flouropolymer binders
Newale, Ashish	J. Gore	anewale	
Panda, Pratikash	R. Lucht	ppanda	
Park, Jeongmoon	S. Heister	park469	Development of Vortex Pair Swirlers for Aerospace Applications
Park, Sunny	S. Heister	park199	Modeling Two-phase Flow with Stochastic Coalescence/breakage Model
Pfeil, Mark	S. Son, S. Heister	mpfeil	MS: Effects of Ammonia Borance on the Combustion of Ethanol
Pfeil, Teandra	L. Groven, T. Pourpoint	tlevans	Solution Combustion Synthesis of Cobalt Catalysts for the Hydrolysis of Sodium Borohydride
Pinnola, Marissa	N. Key	mpinnola	Characterizing the Forcing Functions and Response of an Embedded Rotor at Resonance Conditions
Pohl, Nicholas	N. Key, J. Chen	npohl	



Reese, David	S. Son	reesed	MS: Inclusion of Nanostructured Materials in Composite and Double Base Propellants
Renslow, Peter	S. Son	prenslow	
Roa, Mario	R. Lucht	mroa	Subject: Laser diagnostic techniques for distributive combustion with applications to gas turbines
Rodrigues, Neil	P. Sojka	rodri190	Spray Atomization of Non-Newtonian Impinging Jets
Rubio, Mario	S. Son	rubio0	

MJZL CURRENT STUDENTS (cont.)

Student	Advisor	Email ....@purdue.edu	Thesis Topic
Sane, Anup	J. Gore	asane	A Numerical and Experimental Study of Solid Carbon Conversion Processes in Energy Systems and Combustion
Sane, Mugdha	J. Gore	msane	Subject: Combustion
Satija, Aman	R. Lucht	asatija	

Seebald, Paul	P. Sojka	pseebald	Subject: Transcritical Injection
Shark, Steve	S. Son, S. Heister	sshark	Hybrid Rocket Combustion: Advanced Fuel Additives and Mixing Studies
Shipley, Kevin	W. Anderson	kevin.j.shipley.1	Computational and Experimental Investigation of Transverse Combustion Instability
Sippel, Travis	S. Son	tsippel	Hypergolic Ignition and Stabilization of Metal Hydride-based Propellants
Sircar, Indraneel	J. Gore	isircar	Subject: Experimental investigation of coal and biomass gasification for liquid fuel synthesis
Slabaugh, Carson	R. Lucht, S. Meyer	cslabau	High-Pressure TAPS Flame Visualization
Smith, Natalie	N. Key	smith773	Experimental Investigation of Vane Clocking Effects on Stall Performance and Unsteady Boundary Layer Development in a Multistage Compressor
Snyder, Sharon	P. Sojka	snyder22	Secondary Atomization of Elastic Non-Newtonian Liquid Drops
Sun, Lijian	S. Fleeter	lsun	CFD Modeling of Wind Turbine Wake in Wind Farms
Tanvir, Saad	L. Qiao	stanvir	
Terry, Brandon	S. Son	terry13	Subject: Nanoscale silicon composite energetic materials.
Thompson, Andrew	S. Heister	thomps79	Flashing of High Temperature Fuels in Internal Flow Passages

MJZL CURRENT STUDENTS (cont.)

Student	Advisor	Email ....@purdue.edu	Thesis Topic
Troiani, Alex	S. Son	atroiani	Effects of Fuel Additives on Combustion Distribution and Stability
Wang, Weining	J. Chen	wang1304	
Wierman, Matt	W. Anderson	mwierman	Subject: Nonlinear predictive model of rocket engine combustion instability
Wiest, Heather	S. Heister	hwiest	Subject: Testing nozzle performance for supersonic business jet applications
Yang, Yicheng	J. Gore	yang479	
Zaseck, Chris	S. Son, T. Pourpoint	czaseck	Development of High Performance Paraffin-Based Hybrid Fuels
Zhou, Nina	J. Chen	zhou9	

Students in Prof. Pourpoint's Hybrid Rocket Flight Experiment Class Prepare Rocket for Ground Testing

MJZL RECENT GRADUATES

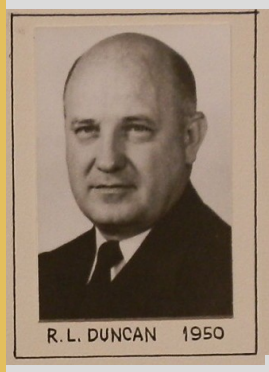
Student	Advisor	Thesis Title	Career Destination
Bajaj, Chetan, MSME 2012	J. Abraham	Computational Investigations of Ignition Delay and Flame Lift-off in Diesel Jets	Cummins
Chang, May Lin, MS 2011	S. Fleeter	An Interactive Tool to Predict VAWT Performance Using Streamtube Models	
Dambach, Eric, PhD 2011	S. Heister	Hypergolic Ignition of Monomethyl Hydrazine with Nitric Acid	SpaceX
Dechelette, Alexis, PhD 2011	P. Sojka	Predicting drop size distributions for transient sprays	
Deshpande, Kedaresh, MSME 2011	J. Gore, Y. Zheng	An Experimental Study of Ammon ia Borane Based Hydrogen Storage Systems	
Finney, Heather, MS 2011	P. Sojka	Deep Water Crude Oil/Natural Gas Jet Flows	Purdue, working on PhD, MJZL
Harvazinski, Matthew, PhD 2012	W. Anderson	Modeling Self-Excited Combustion Instabilities Using a Combination of Two– and Three-Dimensional Simulation	AFRL Phillips Lab
Hedman, Trevor, PhD 2012	S. Son, R. Lucht	Experimental Observation and Modeling of Solid Composite Propellants	NAWC, China Lake, CA
Hinkelman, Matthew, MS 2011	S. Heister	Development and Testing of Dicyclopentadiene Based Solid Composite Propellants	CA
Iwanicki, Michael, 2012	T. Pourpoint		
Janesheski, Robert, MS 2011	S. Son	Detonation Failure Characterization of Non-Ideal Explosives	Rolls-Royce, Indianapolis, IN
Kennington, Jeff, MS 2011	S. Frankel	Design and Optimization of a Novel Cavopulmonary Assist Device for Fontan Circulation: CFD and PIV Studies	
Lamont, Warren, PhD 2012	R. Lucht, W. Anderson	Experimental Study of a Distributed Combustion System for Stationary Gas Turbines	Power Systems Mfg. in FL
Lastufka, Arin, MS 2011	W. Anderson	Effect of Diluent on Gelled Monomethylhydrazine Ignition and Dual Flame Behavior	
Lee, Andrew, PhD 2011	P. Sojka	High-shear granulation	Rolls-Royce Indy
Mallory, Jennifer, PhD 2012	P. Sojka	Jet Impingement and Primary Atomization of Non-Newtonian Fluids	Western New England Univ. in MA
Massaro, Matt MS 2012	S. Son	Coal Fine Utilization and Analysis Using Municipal Solid Waste (MSW) Plastics and Other Binders	Gamma Technologies, Inc.
McPherson, Paul, MS 2011	S. Fleeter		
Miklaszewski, Eric, MS 2011	S. Son	Oxy-fuel Combustion: Laboratory Experiments and Pilot Scale Tests	PhD at Purdue
Miller, Keith, MS 2012	N. Key	Design of a Centrifugal Compressor Research Facility for Low Specific Speed Applications	SpaceX, CA
Mitchum, Greg, MS 2011	H. Mongia, R. Lucht		
Morgan, Collin, MS 2012	W. Anderson		NASA MSFC
Mukhopadhyay, Saumyadip, PhD 2011	J. Abraham	Ignition and Early Flame Development in Stratified-charge Mixtures	

MJZL RECENT GRADUATES (cont.)

Student	Advisor	Thesis Title	Career Destination
O'Neil, Patrick, MSME 2012	S. Heister	Developments in Processing and Ballistics of Dicyclopentadiene-Based Composite Solid Propellants	Pratt & Whitney in CT
Pomeroy, Brian, PhD 2012	W. Anderson	Measurement and Analysis of Combustion Response to Transverse Combustion Instability	Aerojet in CA
Rankin, Brent, PhD 2012	J. Gore	Quantitative Experimental and Model-Based Imaging of Infrared Radiation Intensity from Turbulent Reacting Flows	AFRL, Dayton, OH
Reeves, Robert V., PhD 2011	S. Son	Control of Ignition and Reaction Behavior in Gasless Reactive Systems Via Microstructural Modification	Sandia in NM
Rettenmaier, Andrew, MS 2012	S. Heister	Erosive Burning of Composite Propellants	Blue Origin in TX
Seshadri, Priya, MS 2011	S. Son	Combustion Characteristics of Nanoenergetic Materials Composed of Aluminum, Nickel Oxide and a Fluoroelastomer	Purdue working on PhD (not MJZL)
Shetty, Dinesh, 2011	S. Frankel		
Snyder, Sharon, MSME 2011	P. Sojka	Secondary Atomization of Elastic Non-Newtonian Liquid Drops	Purdue, working on PhD at MJZL
Solomon, Yair , MS 2012	W. Anderson	Gelled MMH Hypergolic Droplet Investigation	
Talalayev, Anton, MSME 2011	N. Key	On the Renovation of the Three-stage Axial Compressor Research Facility for Compressor Performance Research	
Trebs, Adam, 2012	W. Anderson, S. Heister	The Effect of Boundary Layer Variability on Compression Ramp Injector Functionality	Aerojet CA
Voskuilen, Tyler	J. Gore, T. Pourpoint	A Study of Hydriding Kinetics of Metal Hydrides Using a Physically Based Model	Purdue, Post Doc
Williams, Shae, PhD 2011	I. Hrbud	On the Performance of Radio-Frequency (RF) Electric Propulsion Thrusters	
Xu, Duo, PhD 2012	J. Chen	Experimental Study of Turbulent Stratified Jet	Max Planck Institute
Yan, Allen, MS 2011	S. Son	Validation of Numerical Simulations for Nano-Aluminum Composite Solid Propellants	DSSP, Reno, NV
Yarrington, Cole, PhD 2011	S. Son	Combustion Characterization and Modeling of Novel Energetic Materials: SI/PTFE/VITON and AL/PTFE/VITON	Sandia, Albuquerque, NM
Yilmaztuerk, Ali, MS 2011	P. Sojka	Transient supercritical injection	Clean Air Power San Diego, CA
Zakrajsek, Andrew, 2012	S. Son	Water Blast Mitigation	AFRL, Dayton, OH

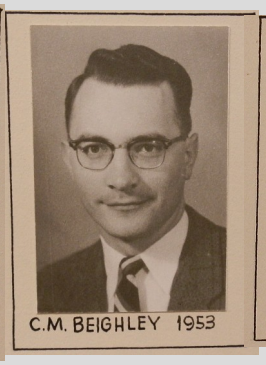
PhD Graduates in Propulsion

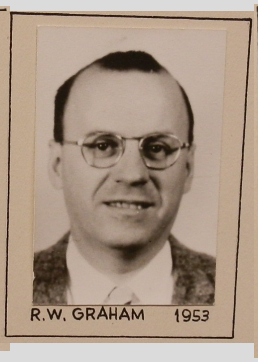
School of Mechanical Engineering


R. L. DUNCAN 1950


W. J. HESSE 1951


C.H. TRENT 1951


C.M. BEIGHLEY 1953


R.W. GRAHAM 1953


S.V. GUNN 1953


B.A. REESE 1953


J.H. FISHER 1954

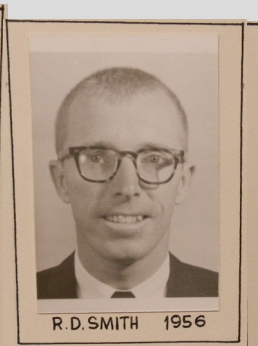

E.L. KATZ 1954

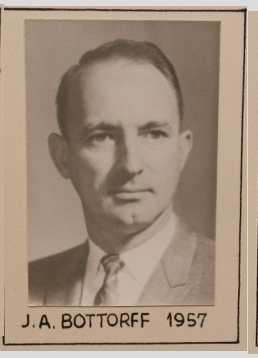

E.N. PETRICK 1955


D.E. ROBISON 1955

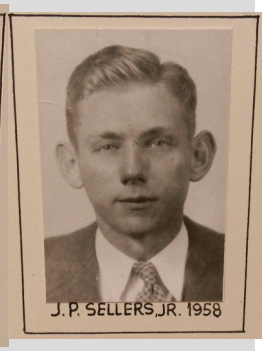

J.M. BOTJE 1956

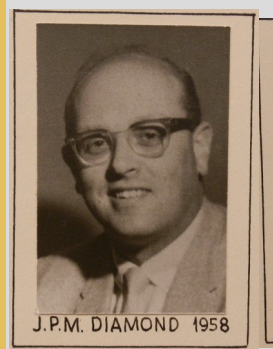

A.B. GREENBERG 1956

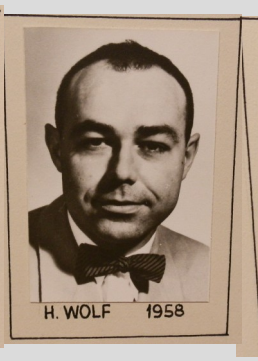

R.D. SMITH 1956


J.A. BOTTORFF 1957


J.R. OSBORN 1957

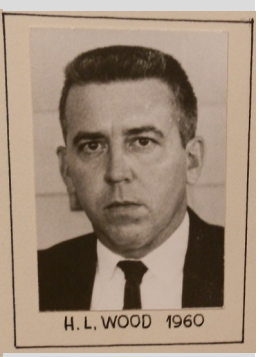

J.P. SELLERS, JR. 1958


J.P.M. DIAMOND 1958


H. WOLF 1958


D.A. CHARVONIA 1959


D.G. ELLIOTT 1959

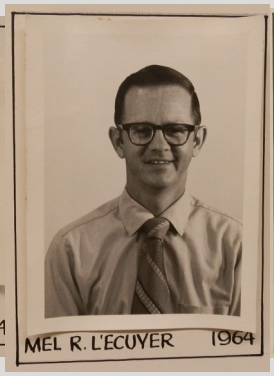

H.L. WOOD 1960

Maurice J. Zucrow Laboratories

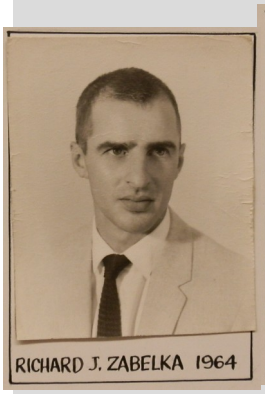

D.L.EMMONS,JR. 1962


J. D. HOFFMAN 1963

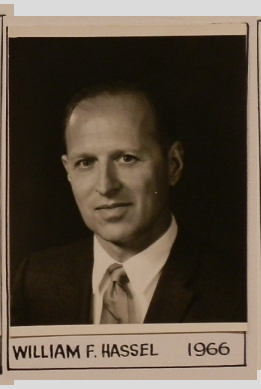

JOHN M. BONNELL 1964

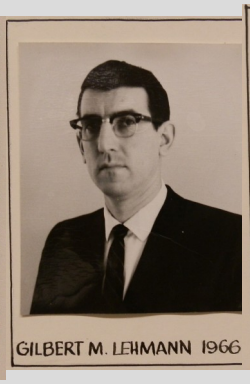

MEL R. L'ECUYER 1964


JAMES G. SKIFSTAD 1964


RICHARD J. ZABELKA 1964


H. DOYLE THOMPSON 1965


WILLIAM F. HASSEL 1966


GILBERT M. LEHMANN 1966


GEORGE R. SCHNEITER 1966


RICHARD J. BURICK 1967


DONALD L. CRABTREE '67


WILLIAM ALLEN 1968


RONALD L. DERR 1968


B. W. FARQUHAR 1968


STUART D. KERSHNER 1968


DAVID NORTON 1968


JOSEPH F. REGAN 1968


ROBERT L. STRICKLER '68

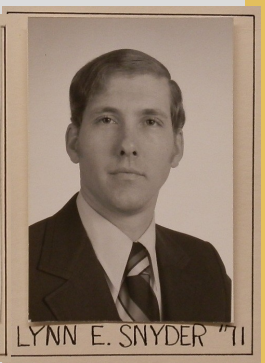

RENALDO JENSEN 1970


JOHN C. VAUGHAN 1970


MIKE CLINE 1971


ARNOLD ELSBERND '71


PHILIP J. GOEDE '71


LYNN E. SNYDER '71